KNOCKING DETECTION APPARATUS AND DETECTION METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a knocking detection apparatus and detection method that detect, with high precision, the presence of knocking and the timing thereof from changes in ion currents that are detected using spark plugs at the time of combustion of an internal combustion engine.

Description of the Related Art

It is known that ions are generated when fuel is combusted inside the cylinders of an internal combustion engine and that these ions can be measured as ion currents by disposing probes that apply a high voltage inside of the cylinders. Because knocking vibration components are superposed on the ion currents when knocking occurs in an internal combustion engine, the occurrence of knocking can be detected by detecting these vibration components. However, spark noise includes many frequency components superposed on the ion currents, end up being detected as vibration components of knocking, and are mistakenly determined to be knocking even if knocking is not actually occurring.

The following technologies have been disclosed as

technologies to avoid this drawback. First, the technology

disclosed in Japanese Patent No. 3184451 (pp. 2-3, Figs. 1

and 2) (Japanese Published Patent Application 9-228941)

includes a bandpass filter that filters only the knocking

frequency components superposed on the ion currents when

knocking has occurred and a noise bandpass filter that

allows frequency components different from the knocking

frequency components to pass. For example, by blocking

noise resulting from the operation of an injector, when

detected through the noise bandpass filter, using a switch,

a knocking signal is not input to a determination circuit.

In the technology disclosed in JP-A-11-2175 (pp. 3-4,

Figs. 1 and 3), signals based on the ion currents pass

through a high-pass filter, and knocking signals pass

through a filter allowing a specific frequency band to pass.

Only the noise component is separately retrieved, using the

filter obstructing the specific frequency band, the peaks

of both are respectively held, digitally converted, and

imported to control means. Both signals are compared by

the control means, and it is determined whether knocking is

occurring from the compared signals.

Moreover, in JP-A-61-57830 (pp. 3-4, Figs. 1 and 3)

signals obtained through a filter selectively passing

knocking signals based on the ion currents and a filter

selectively passing unique vibration frequencies generated

by the mechanical dimensions of each cylinder are respectively integrated over a predetermined period. Signals indicating the occurrence of knocking are obtained from the ratio of the respective integrated values. The signals are integrated during a predetermined number of revolutions, whereby knocking is detected.

Moreover, in JP-A-11-295188 (pp. 5-8, Figs. 9 to 11) signals based on the ion currents are passed through a high-pass filter and a low-pass filter, whereby only a knocking detection signal is extracted. The knocking detection signal is A/D converted, and a discrete Fourier transform is applied. The resulting frequencies are analyzed to determine whether the signal results from knocking or from noise, and the running state of the internal combustion engine is determined.

As described above, these various technologies have been disclosed. However, in the case of Japanese Patent No. 3184451, even if a signal including the knocking component is detected, it is determined to be invalid if a signal including spark noise is included, and it is mistakenly determined that knocking is not occurring even if knocking is occurring. Also, the ion currents are signals that are small, depending on the running state, and the noise signal becomes large when the operating noise of the injector and external noise, such as from a phone are superposed, so

that knocking cannot be completely detected with the methods of JP-A-11-2175 and JP-A-61-57830.

Also, the prior art uses, as the detection target, time intervals between each ignition as units in relation to knocking detection. Use of these time intervals cannot accurately detect knocking, because knocking appears and disappears in units of time shorter than these time intervals. For this reason, there has been the problem that control methods cannot be made to correspond to the timing of knocking occurrence. Moreover, there have been problems. The resistance of the determination function, with respect to ion current signals whose amplitude has been increased due to the influence of additives added to the fuel, is low. The ion currents have superposed impulse noise including many frequency components. Also, in all of the prior examples, knocking determination precision has been low because the time resolution has been low.

SUMMARY OF THE INVENTION

The present invention has been made in order to solve these problems, and it is an object thereof to detect, with high precision, the occurrence of knocking and the timing thereof with time units narrower than intervals between ignitions, even in a case where the ion currents generated inside the cylinders of an internal combustion engine are

measured and noise is superposed on the ion currents.

A knocking detection apparatus pertaining to the invention comprises: spark plugs disposed in cylinders of an internal combustion engine; ion current detecting means for detecting ion currents flowing in the spark plugs; time-frequency transforming means for setting time intervals, with one or more time overlaps, within a time from ignition by a spark plug in a corresponding cylinder or in another cylinder, until the next ignition, and sampling current values of the ion currents in the respective time intervals to determine the frequency components thereof; knocking detecting means for detecting knocking on the basis of the frequency components; and detection control means receiving running status of the internal combustion engine and controlling the time-frequency transforming means and the knocking detecting means.

A knocking detection method pertaining to the invention includes: ion current detecting means for detecting ion currents using spark plugs disposed in cylinders of an internal combustion engine; time-frequency transforming means for setting time intervals allowing time overlaps within a time from after ignition by a spark plugs in a corresponding cylinder or another cylinder, until the next ignition, and sampling current values of the ion

currents in the respective time intervals to determine the
frequency components thereof; knocking detecting means for
detecting knocking on the basis of the frequency
components; and detection control means for controlling the
time-frequency transforming means and the knocking
detecting means, wherein the detecting control means
receives running status of the internal combustion engine
and controls the time-frequency transforming means and the
knocking detecting means determining frequency components
from sampled values of the ion currents.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a schematic
configuration of a knocking detection apparatus and
detection method according to a first embodiment of the
invention;

Fig. 2 is a block diagram describing ion current
sampling in the knocking detection apparatus and detection
method according to the first embodiment of the invention;

Fig. 3 is an explanatory graph of ion current
detection intervals in the knocking detection apparatus and
detection method according to the first embodiment of the
invention;

Figs. 4(A), 4(B), and 4(C) are explanatory graphs of
time-frequency transformation and knocking determination

function values in the knocking detection apparatus and detection method according to the first embodiment of the invention; and

Figs. 5(A), 5(B), and 5(C) are explanatory graphs of time-frequency transformation and knocking determination function values in a knocking detection apparatus and detection method according to a second embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

Figs. 1 to 4(C) are diagrams describing a knocking detection apparatus and detection method according to a first embodiment of the invention. Fig. 1 is a block diagram showing a schematic configuration of the knocking detection apparatus and detection method, Fig. 2 is a block diagram describing ion current sampling, Fig. 3 is an explanatory graph showing sampled intervals in ion current detection, and Figs. 4(A), 4(B) and 4(C) are explanatory graphs describing the result of time-frequency transformation of ion currents and knocking determination function values.

In Fig. 1, an ignition device 1 includes a publicly-known ignition circuit. An ion current detecting means 2 detects an ion current from the current of a secondary

ignition circuit and is a publicly-known ion current

detection circuit. As described later, time-frequency

transforming means 3 applies a Fourier transform so that

knocking can be determined from an ion current signal, and

knocking detecting means 4 determines the presence of

knocking from the result of transformation by the time-

frequency transforming means 3 and detects the timing of

the knocking.

Detection control means 5 receives the running status

of an internal combustion engine, controls the time-

frequency transforming means 3 and the knocking detecting

means 4, and transforms, in accordance with the running

status of the internal combustion engine, sampled times of

ion current values resulting from the time-frequency

transforming means 3 and an ion current sample number

serving as the target of time-frequency transformation.

The result of detection by the knocking detecting means 4

is given to ignition control means 6, and the ignition

control means 6 controls ignition times in accordance with

the state of knocking.

The time-frequency transforming means 3 includes ion

current sampling means 7 and ion current sampled value

transforming means 8 shown in Fig. 2. The time-frequency

transforming means 3 first determines ion current sampled

values $x(0)$, $x(\Delta T)$, $x(2\Delta T)$, ... from the detected ion

currents with respect to 0, ΔT, $2\Delta T$, ... that are fixed intervals from a starting point determined by the detection control means 5. In this embodiment, a case where $\Delta T = 5\mu s$ is used as an example, but ΔT can be optionally set depending on conditions.

Next, the time-frequency transforming means 3 determines the frequency components $C_n(f)$ in respective time intervals from the sampled ion currents included in the time intervals represented by the set $In = (Tn, Tn+\Delta T, ..., Tn+(M-1)\Delta T)$. The set of time intervals includes overlaps in an amount determined by the detection control means 5. That is, here, the time-frequency transforming means 3 sets, as shown in Fig. 3, a set of time intervals with one or more overlaps of adjacent time intervals, in the time period from the ignition determined by the detection control means 5 until ignition occurs in a cylinder, samples the ion currents with respect to each time interval, and determines the frequency components of each ion current sample. In the present embodiment, an example is described in which the total number of intervals in the set, M = 256, and time intervals are recursively defined as $T_{n+1} = T_n+(M/K)\Delta T$ (where K = 8 and n = 0, 1, 2, ...), but the effectiveness of the invention is not limited to these values.

A specific way of determining the frequency

components uses a fast Fourier transform (FFT) using a Hanning window W(m) of an order M, defined by the following equation, as one example in this embodiment, but the effectiveness of the invention is not limited to this selection of the Hanning window function.

[Equation 1]

$$w(m) = \{1-\cos[2\pi(m+1)/(M+1)]\}/2 \quad\quad ... (1)$$

Here, $m = (0, 1, 2 \cdots M-1)$, the symbol $\cos(x)$ represents a cosine function of x, and the symbol π represents pi.

With respect to the fixed time intervals In, the frequency components $C_n(f)$ (where $f = 0, 1, 2 \cdots M-1$) are determined by the following equation.

[Equation 2]

$$C_n(f) = \Sigma\{0 \leq m \leq M-1\}\{x(Tn+m\Delta T)w(m)\exp(-2\pi ifm/(M-1))\}$$

$$... (2)$$

Here, the symbol i represents the imaginary unit, and, exp represents an exponential function. Also, with respect to a sequence in the form $\{a(m)\}$, the symbol $\Sigma\{0 \leq m \leq M-1\}\{a(m)\}$ represents an operation that corresponds to the sum $a(0)+a(1)+\cdots+a(M-1)$ of the sequence.

Below, with respect to a logical expression $f(x)$ and the sequence $a(x)$, $\Sigma\{f(x)\}\{a(x)\}$ represents an operation that corresponds to the sum $a(x_0)+a(x_1)+\cdots+a(x_k)$ (where $\{x_0, x_1, x_k\}$ is a set of numbers satisfying the logical

expression f(x)) of the sequence of the set of x, where the logical expression f(x) becomes a true value.

The knocking detecting means 4 does not require all frequency components. Because of the condition that the original ion current sampled values are real numbers, all of the frequency components $C_n(f)$ (where {f = 0, 1, $\cdots$M-1}) are not independent of each other. In the time-frequency transforming means 3, the frequency components $C_n(f)$ are determined only with respect to the values of f necessary to the knocking detecting means 4, which the detection control means 5 determines.

It is commonly known that knocking causes vibrations having as primary components frequencies determined by the shape, pressure, temperature, and molecular weight of a gaseous mixture inside the cylinders. Of those frequencies, the frequency where the amplitude experimentally reaches a maximum is taken as a primary frequency f_0, and frequencies at opposite sides of the frequency f_0, where the amplitudes experimentally reach a minimum, are taken as f^- and f^+. In this embodiment, only the frequency components $C_n(f_0)$, $C_n(f^-)$, and $C_n(f^+)$, with respect to $f_0 = 6$, $f^- = 3$, and $f^+ = 9$, are calculated, but it is also possible to vary this selection in accordance with running status of the engine. Also, the effectiveness of the invention is not limited to these values.

When knocking occurs and vibrations are caused, the absolute value $|C_n(f_0)|$ of the primary vibration component has a large value. (The symbol $|x|$ represents the absolute value of x.) However, the primary vibration component can also have a large value when impulse noise is superposed on the ion current. Thus, in the knocking detecting means 4, the following determination equation is calculated.

[Equation 3]

$$D(n) = (2 \times |C_n(f_0)| - |C_n(f^-)| - |C_n(f^+)|) \qquad \cdots (3)$$

While D(n) takes a large positive value with respect to the sampled ion currents when vibration caused by knocking arises, it becomes possible to suppress the influence of impulse noise. However, when the ion currents themselves are amplified by additives, the value produced by the determination equation (3) is proportional to the ion current intensity coefficient, which is the amplification degree. In order to prevent an erroneous determination resulting from this influence, the determination equation is divided by a standardizing factor C defined by the following equation.

[Equation 4]

$$C_n = [\Sigma\{0 \leq f \leq M/2-1\}\{|Cn(f)|^2\}]^{(1/2)} \qquad \cdots (4)$$

In this manner, a determination function E(n) having high resistance to the superposition of impulse noise and changes in the ion current intensity coefficient is

obtained from the following equation.

[Equation 5]

$$E(n) = (2 \times |C_n(f_0)| - |C_n(f^-)| - |Cn(f^+)|) / [\Sigma\{0 \le f \le M/2 - 1\}\{|C_n(f)|^2\}]^{(1/2)} \quad \dots (5)$$

In the present embodiment, the determination function value is compared to a preset threshold Th, but the determination function may be determined by a similar function meeting the above-described impulse noise resistance.

Figs. 4(A), 4(B), and 4(C) show results applied to specific data of this embodiment. The determination function values shown in Fig. 4(C) are obtained from the ion current shown in Fig. 4(A), and knocking can be reliably determined by making the threshold Th 0.1. The change in the intensity of the frequency components catches the vibration generated by knocking, the values of the determination function greatly exceed the threshold, and knocking is clearly detected. It should be noted that, although in the described example Th = 0.1, in this embodiment, the effectiveness of the invention is not limited to this value.

Second Embodiment

Figs. 5(A), 5(B), and 5(C) are explanatory graphs describing ion current time-frequency transformation results and knocking determination function values in a knocking detection apparatus and detection method according

to a second embodiment of the invention. In the first

embodiment, the frequency components were determined by a

fast Fourier transform using a Hanning window function, but

in the present embodiment, the window function of equation

6 is used to obtain a Gabor wavelet component.

[Equation 6]

$$w(m) = \exp(-L(m-(M-1)/2)^2) \qquad \qquad \ldots (6)$$

Figs. 5(A), 5(B), and 5(C) show the results when

equation 6 is applied to specific data for this embodiment,

and show that the occurrence of knocking greatly exceeds

the threshold Th = 0.1 and can be determined. Thus, even

in this embodiment, knocking is clearly detected, as in the

first embodiment. It should be noted that, although L =

$800/(M-1)^2$ was used as an example for L in equation 6 for

this embodiment, the effectiveness of the invention is not

limited to this value.

As described above, the knocking detection apparatus

of the invention comprises: spark plugs disposed in

cylinders of an internal combustion engine; ion current

detecting means for detecting ion currents flowing in the

spark plugs; time-frequency transforming means setting time

intervals with overlaps, within a time from after ignition

by a spark plug in a corresponding cylinder or in another

cylinder, until the next ignition, and sampling current

values of the ion currents in the respective time intervals

to determine the frequency components thereof; knocking detecting means for detecting knocking on the basis of the frequency components; and detection control means for receiving running status of the engine and controlling the time-frequency transforming means and the knocking detecting means. Thus, the knocking detection apparatus of the invention can precisely grasp the distribution of constantly changing combustion energy and can determine knocking and precisely detect the time of occurrence of knocking.

The knocking detection method of the invention includes: ion current detecting means for detecting ion currents using spark plugs disposed in cylinders of an internal combustion engine; time-frequency transforming means for setting time intervals with overlaps within a time from ignition of a spark plug in a corresponding cylinder or in another cylinder, until the next ignition, and sampling current values of the ion currents in the respective time intervals to determine the frequency components thereof; knocking detecting means for detecting knocking on the basis of the frequency components; and detection control means for controlling the time-frequency transforming means and the knocking detecting means, including detecting knocking by the detecting control means receiving running status of the internal combustion engine

and controlling the time-frequency transforming means and the knocking detecting means to determine frequency components from sampled values of the ion currents. Thus, the knocking detection method of the invention can detect knocking without mistaken operation with respect to noise from different time intervals, can detect knocking without mistaken operation with respect to fuel where the ion current intensity coefficients are different, and enables control of an internal combustion engine in accordance with the occurrence and timing of knocking.